Geoindicator Scoping Report for Ozark National Scenic Riverways (Strategic Planning Goal Ib4)

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EXECUTIVE SUMMARY

The National Park Service held a Geoindicators scoping meeting for Ozark National Scenic Riverways (OZAR) at park headquarters in Van Buren, Missouri, December 5-6, 2001. The purpose of the meeting was to bring together park staff, geoscientists, and other resource specialists to address the issue of human influences on geologic processes at OZAR. The group used institutional knowledge to inventory geologic processes active in the park and to identify known human activities affecting those processes, satisfying the first and second objectives of Government Performance and Results Act (GPRA) Goal Ib4, respectively. This summary report completes the objective of GPRA Goal Ib4 and is designed to be a tool for future OZAR management decisions as well as a pilot summary for similar parks having fluvial and karst processes within the National Park Service (NPS).

Major geologic processes occurring at Ozark are being influenced by human activity. Humans have modified the landscape around the rivers and caves and consequently have modified the geologic system. This system is dynamic and capable of noticeable change within a human life span (less than a century).

Geoindicators are measurable, quantifiable tools for monitoring rapid change in abiotic systems to help determine ecosystem health and stability. Of the 27 geoindicators that form the basis of evaluating geologic systems, sixteen were selected as applicable to Ozark National Scenic Riverways. Of these sixteen, the following three were identified as processes having the most importance to the ecosystem of the park, the greatest impact from human influence, and the highest level of management significance to the park:

- **Karst Activity**: Surface water runoff, groundwater contamination, visitor impacts, and increasing building and construction have all impacted the caves and other karst features in the park.

- **Surface Water Quality**: Agricultural use of water, including runoff and animal waste lagoons, and increased urbanization are having profound impacts on the park ecosystem.

- **Soil and Sediment Erosion**: The construction of roads and parking lots, logging of forests with replacement by agriculture, and human impacts from foot traffic, vehicles and domestic animals (esp. horses) have increased soil erosion.

The scoping meeting identified six other geoindicators that are or have potential to become critical management issues for OZAR. These are: stream channel morphology, stream sediment storage and load, streamflow, groundwater quality, groundwater chemistry in the unsaturated zone, and soil properties. The increase in human activity, whether is comes from agriculture, timbering, house construction, commercial development or recreational activities, is one of the most significant and difficult challenges park managers must face.

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1.0 Recommendations

Recommendations are not listed in order of priority. However, geoindicators that rated high for all three categories (importance to natural ecosystem processes, human impact on geologic processes and significance to park management) might be used as a first cut for prioritizing projects.

Of the 27 geoindicators (See Section 3.3, Appendix 4), 16 were recognized as features or processes that are active in Ozark National Scenic Riverways. Nine of the 16 geoindicators (Table 1) rated "High" in significance to park management. Three of the geoindicators - "Surface water quality," "Karst activity," and "Soil and sediment erosion" - had the highest possible ranking ("High" in all three columns). Two other indicators, "Groundwater quality" and Groundwater chemistry" rank "High" in all three columns if only local human impacts are considered (middle column) and moderate if human impacts are considered parkwide. Two other geoindicators, "Stream channel morphology" and "Stream sediment storage and load" are high in importance to the park ecosystem and to park management, but moderate in importance to human impacts. Likewise, "Streamflow" and "Soil properties" rank low in human impact but otherwise, high.

The following is a summary of the needs and recommendations determined for each of the 9 geoindicators that are of high concern to park management. Since several of these geoindicators are interrelated (e.g. Karst activity-Surface water quality-Groundwater quality) the recommendations for one may be applicable to several others.

Karst Activity (H-H-H)

- Apply a holistic, multi-disciplined approach to karst studies
- Determine the most important karst systems to monitor
- Educate the public to the problems and dangers of polluting the aquifer
- Develop site specific bulletins for caves and specific to OZAR
- Develop maps showing volumes of spring flows and how rapidly pollution spreads
- Institute a program to inventory springs, measuring or estimating spring flow
- Determine recharge areas of springs
- Determine the age of groundwater discharge at springs
- Obtain sinkhole data such as location, size, drainage system and condition
- Study air quality in caves, especially CO_2 and moisture
- Monitor air quality in caves to determine human impacts
- Study the human impacts on cave air (esp. CO_2 and moisture)
- Hire person to monitor air quality in caves (GIP?)
- Inventory/study human impacts on caves from:
    - Logging (selective cutting, clear cutting, thinning, chip mills)
    - Mining, quarrying, exploration, exploration drilling
    - Location of pipelines
    - Impacts of horses, ATVs, trash, and sewerage
    - PCBs from old transformers

<u>Surface Water Qualit</u>y (H-H-H)

- Obtain more complete data analyses of water samples to measure both physical and biological parameters
- Study impacts from agriculture and logging outside park
- Locate, inventory, and characterize mining operations in drainage basin, including instream gravel mining, and identify impacts
- Study impacts of human activities inside the park
- Study water quality of runoff from streets and roads, trails, sidewalks, and parking lots

<u>Soil and Sediment Erosion</u> (H-H-H)

- Develop map and database of existing roads (active and abandoned) and trails
- Establish photography program: photo points and digital photography to monitor changes
- Study impacts of ATVs and delineate areas that should not be used by ATVs (or by horses)
- Convene group to identify erosion issues and formulate solutions
- Develop reclamation program for roads and trails
- Gather statistics on human use (e.g. roads, trails, horses, canoes, ATVs, etc.)

<u>Stream Channel Morphology</u> (H-M-H)

- Develop a plan for bank stabilization and a dike system at Big Spring to control flooding
- Evaluate the use of cedar tree revetments for flood control
- Inventory the status and vulnerability of campgrounds to flooding
- Incorporate stream profile data into GIS
- Examine historical aerial photos to determine changes in stream morphology through time
- Study impacts of levies, bridge abutments and armoring to channel morphology

<u>Stream Sediment Storage and Load</u> (H-M-H)

- Study bottom loads, especially why are the bottom loads for the rivers changing from fines to more gravels?
- Locate and characterize any mine tailings piles (Pb-Zn): size, shape, composition and quality
- Look at sources of sediment influx (e.g., breached or leaking tailings ponds; bank erosion, agriculture, etc.)

Groundwater Quality (H-M-H)
(See also: Karst Activity)

- Synthesize current existing groundwater data
- Develop a plan for monitoring water wells on lands outside the park
- Continue dye-tracing program
- Establish a program of routine and repetitive sampling of springs

Groundwater Chemistry in the Unsaturated Zone (H-M-H)

- Same recommendations as for Karst activity and Groundwater quality.

Streamflow (H-L-H)

- Model stream flow regimes both with human influence and without human influence
- Quantify information on flooding and major flood events: occurrence, extent, location, damage, costs, etc.)

Sediment Sequence and Composition (H-L-H)
("Soil Properties")

- Research soil characteristics and properties such as grain size distribution, surface modifiers, and compactability
- Determine depth to bedrock at various locations
- Develop new Geoindicator called "Soil Properties"

2.0 Discussion

2.1 Purpose of meeting and park selection

A geoindicators scoping meeting was held at the headquarters of Ozark National Scenic Riverways in Van Buren, MO, December 5-6, 2001. The purposes of the scoping session were to: (1) determine the significant geologic features and processes that shape the ecosystems of the park, (2) identify the human influences on those features and processes, (3) determine the significance they have on the management of the park, and (4) identify inventory, monitoring and basic research needs. Human influences in parks not only include visitor impacts, but also park management practices and developments, land use adjacent to parks (e.g., urbanization, agriculture, recreational uses, etc.), and global issues such as climate change and global warming.

Ozark National Scenic Riverways was created "for the purpose of... preservation of the Current River and Jacks Fork River in Missouri as free-flowing streams..." (78 Stat. 608, OZAR enabling legislation). The primary natural resources of the park are the rivers, springs, cave and karst, and surface and groundwater. This park was selected as a participant in the geology evaluations because of these unique geologic resources and the high degree of potential and on-going human impacts to these resources. Management goals under the Government Performance and Results Act include only 20% of the parks in the National Park System. Hence, information gathered at this park may also be used to represent other parks with similar riverine resources or patterns of use, especially when the findings are evaluated for Servicewide implications.

2.2 GPRA Goal Ib4 Background Information

In 1999, the Geologic Resources Division (GRD) and the NPS Strategic Planning Office cooperated to develop a Servicewide geologic resource goal as part of the Government Performance and Results Act (GPRA). The NPS Goal Ib4 states, “Geological processes in 53 parks [20% of 265 natural resource parks] are inventoried and human influences that affect those processes are identified.” The Ib4 goal is a knowledge-based goal designed to improve the capabilities of park managers to make more informed science-based management decisions regarding geologic resources. It was the intention of the goal to be the first step in a process that would eventually lead to the mitigation or elimination of human activities that severely impact geologic processes, harm geologic features or cause critical imbalance in the ecosystem.

2.3 Geoindicator Background Information

It may be difficult in any particular environment or ecosystem to separate the human influences from the geologic ones. To assist in this task, the concept of “geoindicators” was introduced to NPS resource management as a new ecosystem management tool for park planning. The basic geoindicators tool is a compiled checklist of geological indicators of rapid environmental change. These indicators, developed by the International Union of Geological Sciences, provide

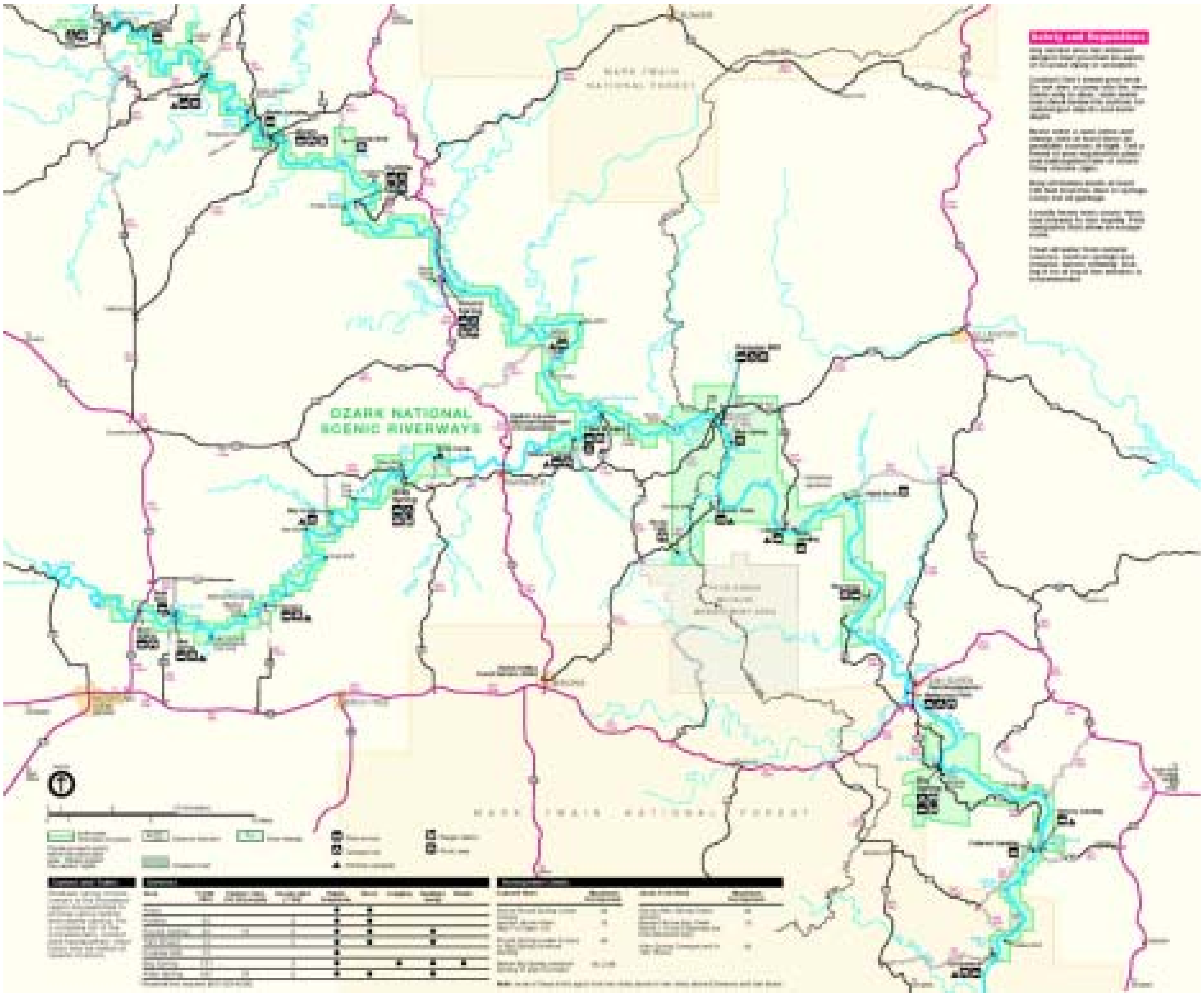

Figure 1: Area Map Ozark National Scenic Riverways

a science-based method to assess rapid changes in the natural environment. The list includes 27 earth system processes and phenomena that may undergo significant change in magnitude, frequency, trend, or rates over periods of 100 years or less and may be affected by human actions (Section 3.4, Appendix 5). Some are single parameters, such as shoreline position, and others are an aggregate of several measures such as groundwater quality. Examples include streamflow and channel morphology, groundwater level, soil and sediment erosion, frozen ground activity, lake level and salinity, and slope stability.

Geoindicators measure both catastrophic events and those that are more gradual, but evident within a human life span. To an extent, geoindicators may be a measure of ecological health. The NPS uses the geoindicators concept as the basis for discussing and evaluating the state of the environment, ecosystem changes, and how humans are affecting natural systems. Geoindicators are invaluable tools to help focus non-geoscientists on key geologic issues, help parks anticipate what changes might occur in the future and identify potential management concerns from a geologic perspective.

The NPS uses geoindicators as a proxy for geologic process. Geoindicators are not geologic processes. However, there is a strong correlation between the two. Because geoindicators represent a landscape measurement, one that concentrates on physical (including chemical) processes and their interactions with biologic and human components, they are uniquely suited to assess human versus natural causes of change in the ecosystem.

2.4 Results of Geoindicators Scoping Meeting

The results of the Geoindicators meeting is recorded in Table 1. Of the 27 Geoindicators, 16 were determined to be applicable to Ozark National Scenic Riverways. Each Geoindicator was evaluated during the discussions as to its importance to the ecosystem, the impact or influence human activity has on that process or feature, and its importance to park management.

Table 1: Geoindicators for Ozark National Scenic Riverways

Geologic (ecological) importance, degree of human influence, and management significance of selected geoindicators

Geoindicators Identified in the Ecosystem	How important is the process to the park's ecosystem?	Rank the human impact on the geologic process	Significance to park management
SURFACE WATER			
1. Stream channel morphology	**H**	**M**	**H**
2. Stream sediment storage and load	**H**	**M**	**H**
3. Streamflow	**H**	**L**	**H**
4. Surface water quality	**H**	**H**	**H**
5. Wetlands extent, structure, hydrology	**M**	**M**	**M**
GROUNDWATER			
6. Groundwater quality	**H**	**M (H)**	**H**
7. Groundwater chemistry in the unsaturated zone	**H**	**M (H)**	**H**
8. Groundwater level	**L**	**L**	**L**
9. Subsurface temperature regime	**L**	**L**	**L**
CAVES			
10. Karst activity	**H**	**H**	**H**
11. Surface displacement	**L**	**L**	**L**
SOILS			
12. Soil quality	**H**	**L/M**	**L**
13. Soil and sediment erosion	**H**	**H**	**H**
14. Sediment sequence and composition (Soil Properties)	**H**	**L**	**H**
HAZARDS			
15. Slope failure (landslides)	**L**	**L**	**L**
16. Seismicity	**M**	**L (N/A)**	**L**

H – HIGHLY influenced by, or with important utility for
M – MODERATELY influenced by, or has some utility for
L – LOW or no substantial influence on, or utility for

2.4.1 Description of Geoindicators for Ozark National Scenic Riverways

The following discusses only those nine Geoindicators that are ranked "High" in importance to management: Stream channel morphology, Stream sediment storage and load, Streamflow, Surface water quality, Groundwater quality, Groundwater chemistry in the unsaturated zone, Karst activity, Soil and sediment erosion, and Sediment sequence and composition. Except for the Wetlands Geoindicator, the remaining geoindicators are ranked "Low." Wetlands Extent, Structure, Hydrology is ranked "Moderate." The various aspects of this indicator are adequately covered by the discussions of the others.

The order of discussion is by apparent importance as given by the ranking (e.g., H-H-H first, then H-M-H, etc.) down the table.

2.4.2 Surface Water Quality (H-H-H)

Ozark National Scenic Riverways was, among other reasons, established to conserve and interpret natural and scenic values, to preserve the Current and Jack Fork rivers as free-flowing streams, to preserve the springs and caves along the riverways, and to provide for public recreation. The park receives about 1.5 million visitors each year (FY 2001: 1,497,988). Summer use is typically 2,000-3,000 visitors per day, but may be as high as 10,000 visitors on July 4th. The quality of the water in the two rivers is of utmost importance both for the ecosystem and for the enjoyment of the visitor. Surface water quality of OZAR is generally excellent and has not been a problem. And it is the excellent water quality that draws people to the park and is responsible for the extremely diverse aquatic ecosystem. Water quality, therefore, is of critical significance to the OZAR ecosystem and management.

Externally, the water quality is being impacted by several activities. Agricultural practices have impacted the water quality because fertilizers and pesticides wash off the land surface into tributary streams and into the two major rivers. Chemical fertilizers add nitrates and other plant nutrients to the soil as well as lower the pH in the adjacent streams. This can result in algal blooms, eutrophication, and vegetative die-off. Loss of spring flow due to dewatering of aquifers could increase the concentration of nutrients and contaminants in the water of the springs. Subsurface conduit flow can potentially deliver contaminants quickly and at unpredictable locations. The locations of these conduit systems and associated recharge areas are not well understood. Agriculture also strips the land of native vegetation resulting in an increase in runoff and more sediment deposited in the rivers. The increase in sediment clouds the water and can adversely affects the riverine biota.

Logging strips the land of trees resulting in an increase in runoff, erosion and sedimentation. Increasing urbanization around the park has resulted in a increase in the influx of hydrocarbons, such as motor oils, lubricating oils, brake fluid, coolant, and fuels, into the river systems. Runoff from parking lots, garages, and sidewalks flows into sewers and eventually into the rivers. The number of septic and sewerage systems has increased with increasing population. Some of these impacts will be discussed below under Groundwater quality and Karst activity.

In the park the water quality of the Current and Jack Fork rivers is directly affected by visitor use. Visitors bring in food, beverages, and containers to float or paddle down the rivers contributing to increased organic matter and trash. There also is an increase in fecal coliform from visitors using the rivers as outdoor toilets. Oils and dirt from the skin and clothes of thousands of visitors adversely impact the surface water quality. The use of horses near the banks results in the introduction of horse manure into the rivers. Soil and bank erosion occurs from visitors putting their tubes, canoes, kayaks, and rafts into the rivers and also from horseback riding near river banks.

Water quality is of the utmost importance to the park since the purity of the water in the spring-fed rivers is both vital to the wildlife and vegetation and also it is a great part of the attraction of the rivers to the visitor. A serious decline in surface water quality will negatively impact the riverine ecosystem and visitation.

Monitoring and Research

Long term monitoring means gathering more data with a greater attention to capturing storm and flooding events. Basic research is needed to determine the potential for lead contamination through karst connections and through bioaccumulation pathways. Also, there is a need to develop an understanding of the links between water quality and biological responses such as continuing efforts to identify bacteria in the stream water and determine their origins. The current lack of a structured sampling plan with appropriate protocols constrains the ability of researchers to address these issues. There is a need to optimize water quality sampling methods and designs to obtain useful and meaningful data.

2.4.3 Karst Activity (H-H-H)

The Geoindicators for karst, surface water, groundwater, and soils are so interdependent that discussions of human impacts to karst will apply to many other Geoindicators as well. The karst terrain in southern Missouri is the foundation or framework of the entire river system and the dependent ecosystem. The many large springs along the Current River, and consequently the park, would not exist were it not for the karst. The present ecosystem has developed in response to the karst and it is imperative that the quantity and quality of water moving through the karst system be maintained to preserve the park ecosystem. Therefore, importance to the park ecosystem is high. Most of the caves inside the park have very short source areas and do not extend beyond the boundaries of the park. However, a few caves do have water sources that originate outside the park.

In contrast most of the recharge area of the springs comes from outside the park. Sixty per cent of the flow of the Jacks Forks and Current Rivers comes from seven major springs and 51 smaller springs within the drainage basin. Big Spring, one of the largest springs in the United States, has an average flow of 289 million gallons of water per day. The maximum recorded flow in one day was 840 million gallons in June 1928.

The potential for severe human impact on the OZAR karst system is enormous. The following are the major impacts discussed at the scoping meeting.

Agriculture. The drainage area of the Jacks Fork and Current Rivers and the recharge areas for the springs that feed the rivers is still primarily forest. However, the forest land is being cleared for pasture in many areas. Whatever is deposited on the surface, very likely percolates through the dolomitic bedrock into the groundwater and into the karst system: herbicides, pesticides, animal wastes, fluids associated with agricultural equipment, etc. Since water monitoring is primarily for dissolved cations and anions and not for organics, the scope of the problem is not known. Land clearing for grazing and grazing in riparian areas adds both organics and inorganic sediment (esp. clay and silt) to the inflow. Although no animal feed lots are presently in the OZAR watershed, there is potential for the development of feed lots in the stream basins and spring recharge area in OZAR.

Logging. Much of the recharge area was forested until logging operations began when the area was settled. Logging has changed the land to different uses, especially agriculture. Logging has occurred as selective cutting, clear cutting, thinning, and cutting for chip mills. The latter is the most destructive since it uses virtually all of the tree, returning very little organic matter to the soil. The result is increased sedimentation, both surficially and into the karst system.

Urbanization. Although the recharge area is not a area of great urban development, there is increasing pressure from human development. The increase in the number of retail businesses such as Wal-Mart is having an impact. Runoff from parking lots prevents water percolation into the subsurface resulting in channeling and erosion. The runoff picks up pollutants such as engine oil, radiator fluid, brake fluid, lubricants, trash, etc. The increase in the number of houses results in more septic systems and sewerage disposal. Sinkholes that have developed on the karst surface are often sites of garbage disposal. Some septic systems discharge into the sinkholes. Contamination from landfills is a threat, although most landfills are being relocated out of the drainage area.

Mineral Development. Mining, quarrying and drilling are potential sources of contamination. Southern Missouri is one of the centers of lead-zinc mining operations in the United States. There is potential for acid mine drainage as pyritic material oxidizes to form sulfuric acid that reacts with the carbonates of the bedrock. Mine wastes (tailings) are held in huge ponds held by earthen berms and dams. Failure of these structures could result in huge amounts of sediment, acidic water, and chemicals used for mineral extraction being injected into the surface waters, groundwater, and the karst system. There have been more than 300 exploration holes drilled for lead-zinc in the Mark Twain National Forest west of Big Spring. Most of these drill holes are located in the recharge area of Big Spring and could potentially introduce toxic drilling fluids into the karst system.

Infrastructure. Roads, pipelines, and drainage systems result in ground disturbance, increased runoff, and the potential for contaminants from ruptured lines. Polychlorinated biphenyls (PCB) from old transformers are toxins that are present but in unknown amounts.

Recreation. All the impacts associated with surface water discussed above apply to karst activity. Increased visitation to caves and springs brings an increase in the amount of trash, human wastes, and foot traffic. People like to touch cave speleothems, introducing lint and oils from the human body and thereby altering the character of the cave formations.

Air Quality. There has been little research into the quality of air in the caves. Human visitation introduces carbon dioxide, moisture, and bacteria from exhaled air.

2.4.4 Soil and Sediment Erosion (H-H-H)

The discussions of soils was a significant portion of the scoping meeting. Soil quality was seen as important to the ecosystem of the park, but not greatly impacted by human activity nor of great importance to park management (Table 1). The park has had little change in soil quality, except possibly in the bottomlands that were cleared for agriculture. Soil quality is fairly good and may actually be improving. Organic matter has never been very high in Ozark soils. The trees do not produce much organic matter. There has been a noticeable loss of fine material (silt and clays) especially in the bottomlands with a increase in gravels. Increasing stream meandering has caused bank cutting which removes the fines while the gravels remain. There is a soils map of the park, but additional detail studies are needed in some areas.

The erosion and loss of soils are not only important to the ecosystem but also have a large human impact component and is of great concern to park management (Table 1). The removing of vegetation for agriculture and logging has great effects over a large area. However, the most detrimental human effects are more local and specific, as listed below:

Roads. There are over 318 miles of roads, 14 miles of horse trails and 48 miles of foot trails in the park. Paved roads are impervious to water infiltration so that water moves off the roads in sheet flow causing rilling and channeling on the sides removing soil as it does so. Likewise, vehicle traffic on unpaved dirt and gravel roads has compacted the road surfaces inhibiting infiltration and promoting increased runoff. However, during high rain events, the unpaved roads themselves become sites of sediment removal, adding to the sediment load. Although, the impacts of roads in the park is not well known at this time, many studies have shown that roads are the primary contributor of sediment to streams within the Ozarks.

In 1991, the park conducted a Roads and Trails Study and Environmental Assessment. The purpose of the study was to inventory and evaluate the road and trail systems. The study was broken down into three categories: roads and traces, horse trails and foot trails. The park proposed close and revegetate rarely used or abandoned trails to vehicular traffic, the remove roads that duplicate other access roads and exclude vehicles from areas having endangered species. The study identified problems with horse trails, set thresholds for use levels for a four year period so that a monitoring program could be set into place and developed criteria by which to evaluate group ride permits. In addition, it was recommended that no new horse trails be established. The foot trails sections identified actions to correct problems on foot trails, the redesign of trails around existing developed areas and the location and themes for potential interpretive trails.

All Terrain Vehicles (ATVs). There is no prohibition of ATV activity in the park. Since most probably do not follow roads the result is compaction of the soil surface and the destruction of vegetation with increased soil and sediment erosion. There is a need to inventory both designated roads and ATV trails to determine the extent of the activity. Aerial photography is a valuable tool in identifying ATV trails. Also, photo points can be established in areas of expected high erosion. The amount of ATV activity can be monitored by establishing ATV check-points when ATVs enter the park.

Other High Impact Areas. Access points for canoes, rafts, and other floatation devices are areas of high soil and sediment erosion. River banks are eroding and sloughing into the channels at these access points caused by human foot traffic, vehicles and trailers, and by the process of putting into the water. Horse traffic causes soil compaction, rutting and bank erosion. There has been an increase in stream meandering with resultant bank cutting, possibly from the destabilization of the banks by human activity. The bank cutting has resulted in a loss of fine material (carried downstream) leaving the gravels in the channel.

Along the Current River, the Cedargrove to Akers area is located on a narrow flood plain. This section of the park is probably the most heavily utilized by ATVs and it also sustains a great deal of horse use. There have been conflicts between canoeists and ATVs which are crossing the river. There are 8 locations on the Current River where river crossings exist in approximately a 7 mile stretch. The river crossings are located in areas of shallow water and where gravel bars have formed. The crossings have been created through frequent ATV and horse activity and were not developed as river fords by the park. In the 8 river crossing locations, there are multiple river entry points. Some of the entry points are incised by as much as 4 feet below the surrounding banks. Repeated impacts have accelerated erosion of the river banks in these areas. Park staff have noted that during heavy weekend use the river is visibly more turbid.

In addition to the river crossings, the area is heavily dissected with unauthorized horse trails. Flagging on trees within the wooded floodplain were placed by horse groups who have begun flagging out their own trails. Horse groups have begun cutting new trails because the ATVs have rutted out the trails that they have been using.

Inventory and Monitoring

An inventory and analysis of roads and trails would help identify problem areas. Without an active program to identify and correct these problems, habitat damage, effects on water quality, and impacts to cave and spring resources will continue. An analysis should identify sources of the sediment and areas where control and prevention of runoff can be implemented. Well-established practices to control and prevent erosion and peak flows can drastically reduce impacts, protecting watersheds and natural flow conditions. These practices include road closures, full decommissioning or road upgrades. Upgrading can modify drainage to reduce the likelihood that a road or trail will act as an extensions of the stream. Paving or asphalt surfacing of high use roads, and closing or reconstructing stream crossings can reduce the influx of sediment. Also, culvert placement or replacement and water-bars may also be useful. Repairs designed for long-term stability are necessary to restore the natural drainage pattern of the immediate area and to eliminate excessive flow which lead to accelerated erosion.

2.4.5 Stream Channel Morphology (H-M-H)

The shape of a stream channel is important to riparian flora and fauna which depend on the size, shape, and bottom characteristics of the channel. Since the park is primarily associated with the

Jacks Fork-Current River System, channel morphology is of high importance to park management. Human impacts are similar to those discussed above. Visitor impacts in addition to bank erosion include the impact of in-stream traffic. In high use areas, there is a considerable amount of disturbance to the bottom sediments as swimmers and waders stir up the bottom. Fine material is put into suspension and removed by the current while gravels remain.

A change in stream channel morphology is indicative of a disturbance in the aquatic ecosystem. Trends in these morphological changes over time can be used as a direct measure of this disturbance. Stream channel morphology is highly significant to the river-corridor ecosystem - the stream ecosystem and the episodically flooded terrestrial, bottomland ecosystem. It provides the physical habitat template for the ecosystem (Jacobson, *et. al*., 2001).

Changes in channel morphology can occur because of land-use or climatic changes in the drainage basins and/or in the riparian zone that affect discharge, sediment supply, and erosional resistance of banks. Consequently, channel morphology can be altered, resulting in different spatial and temporal distributions of depth, velocity, substrate, and cover. In addition to changes in the quality and quantity of available habitat, disturbance regimes can be altered, with potential effects on sedentary organisms like mussels (Jacobson and Primm, 1997).

Channel morphology can be greatly impacted by human activity. At OZAR the historical land-use effect has been great, mainly as a result of riparian land-use change. Since the 1950s, human stresses have been generally decreasing (Jacobson and Primm, 1997; Jacobson, in press). However, recently, new land-use stressors have appeared within the drainage basin. These stressors include the effects of tailings disposal, increased recreational use, poorly engineered road crossings, a new wave of timber cutting, land conversion to grazing, and in-stream gravel mining.

The protocols used by Panfil and Jacobson (2001) identified subtle land-use effects on channel morphology and sediment characteristics in streams tributary to the Current River. Basic understanding developed through work at OZAR and elsewhere in the Ozarks (Jacobson, in press; Jacobson and Pugh, 1997) has been incorporated into stream restoration guidelines used by the State of Missouri. This understanding sets out where inherent instability is likely to overwhelm restoration activities. McKenney (1996; 2001) discusses spatial and temporal controls on creation and degradation of stream habitats, based on monitoring data from Jacobson and Pugh.

Channel engineering can alter the channel morphology. The town of Eminence is located on the Jacks Fork River, east of Alley Spring, and Van Buren is located on the Current River, south of the confluence of the two rivers (Figure 1). Boat ramps, bridge abutments, and levees alter the flow of the rivers and therefore change the channel morphology by creating scouring in some areas and deposition of gravel bars in others. Bank stabilization and a system of dikes for flood control has been used in the park at Big Spring to control flooding and to protect campgrounds. Some campgrounds have been abandoned due to flooding, others have been modified. Revetments using cedar trees have been constructed to control flooding.

Monitoring

Baseline data for changes in channel morphology involve measurements at a wide range of scales. At broad scales, the existing USGS stream gage network provides a long-term (although spatially minimal) record of aggradation, degradation, and morphologic changes. This network not only is valuable in monitoring streamflow but also contributes to understanding long-term geomorphic adjustments (Jacobson, 1995). Low-altitude aerial photography is extremely useful in synoptic assessments of stream channel morphology, specifically in documenting the spatial distribution of gravel bars (Jacobson and Gran, 1999). The remapping of the aerial distributions of gravel bars has contributed to the understanding of sediment routing of the entire park (Jacobson, Panfil, and McKenney, in prep). LIDAR methods may be cost effective. If the goal is to understand the links from stressors to channel morphology and then to the ecosystem, then this work should be coordinated with biological sampling.

At the smallest scale, a network of monitored cross sections can provide precisely quantified channel morphology data. Resurveys provide rates of erosion, deposition, and habitat alteration at scales applicable to aquatic ecosystem communities (McKenny and Jacobson, 1996; McKenney, 1997; McKenney, 2001). Widely distributed stream-channel monitoring cross sections can be used to obtain good spatial representation at the drainage-basin scale with limited representation at the reach scale (Panfil and Jacobson, 2001). Channel cross sections can also be used to monitor changes at scales applicable to stream fauna. The existing network of channel cross sections installed by USGS on the Jacks Fork under the Global Change Program should be resurveyed. Planning for additional cross sections should consider expanding monitoring efforts to include the entire park, either by high-resolution methods at a few sites (McKenney and Jacobson, 1996) or by carefully selected (stratified) cross section sampling at more sites (Panfil and Jacobson, 2001). It is important that long-term, cost-effective monitoring employ a nested set of projects at a range of scales and resolutions.

Long-term stream gauging should be continued with additional stream gauges for tributaries to the Current and Jack Fork Rivers. These gauges supply data on flow, support water-quality evaluations, and provide high-frequency temporal records of geomorphic change. Surveys on the existing Global Change network should be continued (McKenney and Jacobson, 1996) as well as periodically re-survey tributary sections (Panfil and Jacobson, 2001 network), and photograph and analyze aerial photos. This would give OZAR a unique and comprehensive stream-channel morphology monitoring program. Expansion of the high-resolution network to downstream parts of the Current and Jacks Fork rivers would enhance this. Sampling method and design issues include: determining what is the optimum channel morphology sampling network; what hydraulic habitat units need to be monitored; and, what surveying methods would improve efficiency especially in deeper sections?

2.4.6 Stream Sediment Storage and Load (H-M-H)

Sediment storage and load are inextricably tied to channel morphology. Channel morphology is the most prominent indicator of effects of sediment storage and load, and is more directly linked to ecosystem effects. Sediment supply can be measured directly, but it is often not cost-effective to do so. Nevertheless, since sediment load and where it is stored directly effect the river-corridor resources of the park, it is highly significant. Sediment load and storage have been and will probably continue to be highly influenced by human land-use decisions. Sediment storage can be addressed by the channel morphology measures discussed above. Linkage of sediment-related issues to land-use should include quantitative evaluation of sediment loads, which requires sediment load monitoring. Because sediment data are extremely "noisy" over space and time, great care needs to be applied to the decision to invest in this monitoring.

The best linkages to human influences can be established in small drainage basins where transient sediment storage and effects of unmonitored basins can be minimized. Unfortunately, this is at odds with broad spatial coverage. Nevertheless, sediment load data are so fundamental to understanding stream ecosystem dynamics that priority should be placed on initiating collection somewhere in the OZAR system. Long term monitoring should, therefore, include at least one total load sediment station to develop integrated suspended and bed loads.

A particular information gap is particle travel distance. It is an important variable for verifying/calculating downstream rates of movement of gravel bars (Jacobson, Panfil, and McKenney, in prep). Particle travel distance can be estimated through well-constructed gravel tracer experiments.

The bed load and suspended load of the rivers is greatly impacted by the quality and quantity of sediment that comes in. Much of this sediment influx has been discussed above under soil and sediment erosion. Changes in the bed load appear to be related to the number of roads in the park (as a function of increased runoff and erosion).

As previously stated, the stream bottoms seem to be losing fine material and entraining more gravels. However, the gravel story is more complex than the conventional wisdom holds. The Ozark streams have always had large quantities of gravel, so human effects are not as severe as they are often perceived. 4th- and 5th-order streams seem to be aggrading and lower order streams, in general, appear to be degrading and widening, resulting in downstream progression of sediment waves. This model is supported by several lines of evidence, anyone of which by itself is not convincing. The connection is human. It has been assumed that the gravel influx was due to logging in Ozarks. However, more evidence points to riparian land use. Large influxes of gravel have apparently homogenized aquatic habitat and degraded some habitats by filling in pools and cobble interstices. The increase in gravels also may have increased the disturbance impacts felt by benthic invertebrates and fishes.

Abandoned tailings from historic mining are making their way into the streams. The size, shape, composition, and quality differs from natural sediment. The tailings are either leaking from beneath the tailings ponds or from ponds that have been breached. Although, there is some acid influx from the tailings, this does not appear to be a problem at present.

Extraction of gravel material from the river bottoms can have significant effect on the bottom load sediment and on the invertebrates living in the bottom sediment. There has been some historic mining of river gravels and this may still have an impact on the bottom morphology.

2.4.7 Groundwater Quality (H-M/H-H)

Groundwater is an important element of the OZAR ecosystem in that it affects both karst activity and the influx of groundwater into the steams and rivers of the OZAR drainage basin. Of course, groundwater quality plays a vital role in the health and wellbeing of the surrounding population. Most of the human influences were discussed under karst, above. Regionally, groundwater quality is very good. This is because of the relatively small areas of urban development and agricultural land compared to the amount of forested area in the drainage basin. In upland areas, a moderately thick cover of clay-rich subsoil (residuum) derived from weathering of dolomitic rock may filter the water. There is potential for the pollution of groundwater from underground and above ground gasoline and petroleum storage tanks. Water analyses for hydrocarbons such as gasoline, fuel oils, lubricating oils, and gasoline additives such as MTBE should reveal the extent of contamination.

2.4.8 Groundwater Chemistry in the Unsaturated Zone (H-M-H)

This relates to groundwater quality in the area lying above the aquifers. It is of high importance to the ecosystem in that it impacts soil quality. Changes in the groundwater chemistry may indicate human impact from contamination sources discussed above. Although, the unsaturated zone should act as a buffer in areas of residuum cover, increases in nitrates (agriculture) or in heavy metal and pH (acid mine drainage) should be monitored for predicting any long-term trends. The unsaturated zone can both store and transmit pollutants and can be a precursor to their introduction into the groundwater system. Therefore, groundwater chemistry is important to the park management.

2.4.9 Streamflow (H-L-H)

Streamflow is the most fundamental variable for understanding physical, chemical, and biological dynamics in rivers. It is essential and of the highest significance to understanding and managing the Current River and Jacks Fork River. The potential for human influence on streamflow is relatively low, unless the Current River basin is subjected to extensive land conversion (for examples, from timbering to grazing or crops).

Trend analyses on runoff in Ozark streams does not indicate that modern land use has had an observable effect on stream flow (Jacobson and Primm, 1997). Rather, variations in streamflow are related to climatic variation. Nevertheless, even if streamflow itself is not heavily influenced by human actions, sediment supply and chemical quality of the water are heavily influenced by humans and cannot be evaluated without streamflow gauge records.

Baseline streamflow data are being collected at six sites: Highway 17, Alley Spring, and the town of Eminence on the Jacks Fork River; and, on the Current River at Akers Ferry, the town of Van Buren, and town of Doniphan, south of the park. These sites provide a good spatial distribution within the basin. Four of the existing gauges have 8 years or less of record. It is critically important to sustain operations of these gauges to develop useful, long-term records. It may be useful to have another gauging site at the confluence of the Current and Jacks Fork Rivers near Two Rivers campground. There is relatively little gauging data for springs other than

Big Spring. Alley Spring can be calculated, but other major springs like Welch and Blue should be gauged. For long term monitoring suggestions, see Steam Channel Morphology, above.

An information gap in the understanding of streamflow lies in the relationship between streamflow and the karst drainage system. Additional research is needed on the pathways of water discharge to springs and streams.

The streamflow of the both the Jacks Fork and Current Rivers is, for the most part, unimpaired by dams or other control methods. Therefore, the flow is mainly dependent upon rainfall. This is less direct than in some drainage systems in that much of the OZAR river system is spring fed. What influence human activity has on streamflow is difficult to determine, but probably minimal. However, increasing population means more domestic and public-supply wells which equates to lower water levels. One can point to global climate change, but this impact is problematic. It would be useful to examine the data, including historic records on flood events and data from gauging stations, to determine if there are any trends due to an increase in human activity. The understanding of cyclic flood events - 25, 50, or 100-year - is very important to the management of the park.

The U.S. Geological Survey typically resurveys sites after floods and then uses the high-water marks to recreate flood levels. If the surveys are frequent enough, effects of individual floods can be isolated. It is also possible to install crest-stage gauges which give very accurate, low cost water-surface elevations. Documenting the flood while the event occurs is preferable, but logistically difficult. This would involve the use of real-time video, synthetic aperture radar, and/or aerial photography. Occasionally, it is possible to use a boat during the flood and make velocity and depth measurements. The qualitative and visual understanding of floods is very important and can contribute a great deal to understanding what happens during the flood, especially where the high velocities are developed (Jacobson, per. com.)

2.4.10 Sediment Sequence and Composition (H-L-H)

The surficial geologic strata of valley bottoms in OZAR record climatic and historical changes to both the sediment and to hydrologic budgets. The strata and associated landforms create a template that controls some aspects of aquatic and terrestrial ecosystems. The greatest influence is on valley-bottom terrestrial ecosystems due to variations in relative elevation and sediment texture. Surficial geology of the valley bottom should be mapped to achieve the best understanding of controls on the spatial distributions of terrestrial species. On the other hand, the surficial geology does not have the same influence on the terrestrial ecosystem as streamflow has on the aquatic ecosystem.

Monitoring.

Baseline data that would be extremely useful would be surficial geologic maps that subdivide the Quaternary (unlike current USGS 1:24,000 mapping) into allostratigraphic units applicable to terrestrial ecosystems (and cultural resources). This mapping should be at a scale of 1:12,000 scale or greater to resolve spatial characteristics of the major allostratigraphic units (Albertson, Meinert, and Grant). However, as a rule, sediment sequence and composition are not amenable to monitoring because they change so slowly. Surficial stratigraphic records may resolve prehistoric trends and events. Historical and contemporary changes to sediment sequence and composition can be monitored through approaches discussed in channel morphology and sediment storage sections, above.

Major information gaps in understanding the surficial geologic record involve age and correlations of units within the Current River basin and with surficial stratigraphic information from the Mississippi Embayment, Pomme de Terre River valley, Buffalo River in Arkansas, and the Big Piney drainage basin. These gaps could be addressed by systematic stratigraphic studies using radiocarbon, thermoluminescence, and isotope dating techniques. This information could also be used to develop correlations with karst features and cave development history

It was proposed that this indicator be renamed "Soil Properties." Some of this aspect was discussed above under soil and sediment erosion.

3.0 APPENDIX 1: SCOPING MEETING PARTICIPANTS

Ozark National Scenic Riverways Staff

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Victoria Grant	Natural Resource Specialist
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United States Geological Survey

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3.2 APPENDIX 3: OZARK NATIONAL SCENIC RIVERWAYS GEOLOGIC SETTING

3.2.1 Location and Physiography

Ozark National Scenic Riverways (OZAR) is located on the Salem Plateau of the Ozark Plateaus physiographic province in southeastern Missouri. It covers the Current River from Mountain State Park, near the town of Baptist, on the northwest to the town of Gooseneck at the southeast end with a gap of about 5 miles around the town of Van Buren. The Jack Fork River portion extends from west of the town of Buck Hollow northeast to the confluence with the Current River with another approximate 5 miles gap around the town of Eminence, MO.

The Ozark Plateaus is an upland region covering about 50,000 square miles mostly in southern Missouri and northern Arkansas, but extending into southeastern Kansas and northeastern Oklahoma. The boundary is generally defined by the Missouri River to the north, the Mississippi River on the east, the Arkansas River on the south and the Grand and Neosho rivers (Kansas and Oklahoma) on the west. The Ozark Plateaus are subdivided into three subprovinces: the Boston Mountains, the Springfield Plateau, and the Salem Plateau. The Boston Mountains, the southernmost extension of the Ozark Plateau, and located in northwest Arkansas and northeast Oklahoma, form the highest section with peaks greater than 2,000 feet. The Springfield Plateau, located in northwestern Arkansas, northeastern Oklahoma and southwestern Missouri is slightly higher than the Salem Plateau, and is mostly gently rolling plains and hills. Elevations range from about 1,700 feet at its easternmost point to about 1,000 feet at the Kansas border.

The Salem Plateau in south-central Missouri and northernmost Arkansas, is a dissected karst plain consisting of rolling uplands and rugged hills with deeply entrenched stream valleys ranges between about 1000 feet to 1,400 feet in elevation. Locally, elevations vary from about 510 feet on the Current River to 1,273 feet on Wildcat Mountain. There are abundant sinkholes, caves, springs, and losing streams.

Ozark National Scenic Riverways is covered by 16 topographic quadrangle maps. Of these, two geologic quadrangle maps have been completed: Eminence (Orndorff, *et. al*., 1999) and Powder Mill Ferry (McDowell and Harrison, 2000). Much of the following discussion is taken from the text accompanying these maps.

3.2.2 Geologic Setting

The Salem Plateau is underlain by flat-lying to gently dipping upper Cambrian to Lower Ordovician mostly dolomitic strata with scattered knobs of Middle Proterozoic volcanics. The Paleozoic strata are up to 1,800 feet thick and overlay an irregular buried basement surface of Middle Proterozoic rhyolite and granite. The Paleozoic rocks are overlain by unconsolidated surficial deposits of Tertiary to Quaternary age.

3.2.3 Stratigraphy

The basement rocks in the subject area are all granitic and rhyolitic rocks of Middle Proterozoic age and are the southwestern extension of the St. Francois Mountains to the northeast. Radiometric dating gives ages around 1,475 Ma to 1,500 Ma. From oldest to youngest, the Middle Proterozoic units are:

Shut-in Mountain: lava, rhyolite, densely welded (Y_{si})
Sutton Creek Rhyolite: alkali rhyolite to rhyolite, massive (Y_{sc})
Coot Mountain - Lower Unit: interbedded ash-flow tuff, air-fall tuff and lava-alkali rhyolite, to alkali trachyte to trachyte to rhyolite, commonly massive and dense (Y_{cl})
Coot Mountain - Upper Unit: rhyolite to alkali rhyolite to alkali trachyte ash-flow tuff, densely welded, well-developed flow layering (Y_{cu})
Volcanoclastic conglomerate, breccia, and sandstone: interbedded; conglomerate of subrounded cobbles 3"-5" diameter; large pebbles of rhyolite (from Sutton Creek and Upper Coot Mountain) (Y_{vc})

The exposed Paleozoic strata are from oldest to youngest are:

Potosi Dolomite (Upper Cambrian)
Eminence Dolomite (Upper Cambrian-Ordovician)
Gasconade Dolomite (Ordovician)
Roubidoux Formation (Ordovician)

Generally, all the units below the Eminence are locally absent due to erosion or non-deposition over basement topographic highs. In the subsurface, the stratigraphy consists, from oldest to youngest, of the Lamotte Sandstone, Bonneterre Formation, Davis Formation, and Derby-Doerun Dolomite, all Upper Cambrian.

Tertiary and Quaternary deposits lie conformably over the Gasconade Dolomite. These include residuum derived from either the Gasconade or the Roubidoux Formation, terrace deposits, colluvium, and Holocene alluvium.

3.2.4 Structural Geology

Detailed geologic mapping shows that there are many faults in the and around the Ozark National Scenic Riverways. Most of the faults are vertical to steeply dipping, have strike-slip displacement, and trend northeasterly and northwesterly. Joints in the rocks generally are vertical and trend north-south and east-northeast.

3.3 APPENDIX 4: INTRODUCING GEOINDICATORS

What Are Geoindicators?

Geoindicators constitute an approach for identifying rapid changes in the natural environment. An international Working Group of the International Union of Geological Sciences (IUGS) developed geoindicators in order to access common geological processes occurring at or near Earth's surface that may undergo significant change in magnitude, frequency, trend, or rates, over periods of 100 years or less. Geoindicators measure both catastrophic events and those that are more gradual but evident within a human life span. Some geoindicators can provide a record of natural events through time.

The 27 geoindicators are:

1. Coral chemistry and growth patterns
2. Desert surface crusts and fissures
3. Dune formation and reactivation
4. Dust storm magnitude, duration, and frequency
5. Frozen ground activity
6. Glacier fluctuations
7. Groundwater quality
8. Groundwater chemistry in the unsaturated zone
9. Groundwater level
10. Karst activity
11. Lake levels and salinity
12. Relative sea level
13. Sediment sequence and composition
14. Seismicity
15. Shoreline position
16. Slope failure (landslides)
17. Soil and sediment erosion
18. Soil quality
19. Streamflow
20. Stream channel morphology
21. Stream sediment storage and load
22. Subsurface temperature regime
23. Surface displacement
24. Surface water quality
25. Volcanic unrest
26. Wetlands extent, structure, hydrology
27. Wind erosion

Why Are Geoindicators Important?

Ecosystem management, reporting, and planning generally focus on biological issues such as biodiversity, threatened and endangered species, exotic species, and biological and chemical parameters relating to pollution (e.g. air and water quality). Much less attention is paid to the physical processes that shape the landscape—the natural, changing foundation on which humans and all other organisms live and function.

Geoindicators help answer NPS resource management questions about what is happening to the environment, why it is happening, and whether it is significant. They establish baseline conditions and trends, so that human-induced changes can be identified. Applying the geoindicators approach will provide science-based information to support resource management decisions and planning. Geoindicators help non-geoscientists focus on key geological issues, help parks anticipate what changes might occur in the future, and identify potential management concerns from a geological perspective.

Geology and geological processes are integral to park management and planning. For example, the underlying geology and soil influence natural vegetation patterns, and in turn exert a control on biological communities. Geological processes can affect park roads, infrastructure, and facilities. When measures of natural landscape change are omitted from monitoring and planning, the assumption that natural systems are stable, fixed, and in equilibrium is perpetuated. Natural systems are dynamic, and some may be chaotic; change is the rule, not the exception. Monitoring the abiotic components of ecosystems using geoindicators will help to emphasize this point.

The geoindicators approach can be a useful reminder both of the prevalence of natural fluctuations and of the difficulty of separating them from human-induced environmental change. Using geoindicators shifts management actions from response (crisis mode) to long-range planning, so issues can be recognized before they become concerns. Geoindicators may also prove to be useful tools for enhancing interdisciplinary research and communication, a way to connect with others concerned with environmental issues and problems.

How do Geoindicators fit into the National Park Service's strategic plan?

In 1999, the NPS Geologic Resources Division (GRD) and the NPS Strategic Planning Office cooperated to develop a Servicewide geologic resource goal as part of the Government Performance and Results Act (GPRA). The NPS Goal Ib4 states, "Geological processes in 75 parks (36% of 270 natural resource parks) are inventoried and human influences that affect those processes are identified." This goal was designed to increase understanding of geological processes and their functions in ecosystems and to help park managers make more informed science-based management decisions.

This goal is intended to be the first step in a process that will lead to inventory, monitoring, and research, and ultimately focus on the mitigation or elimination of human activities that severely impact geological processes, harm geologic features, or cause critical imbalance in ecosystems.

What is the purpose of a Geoindicators scoping meeting?

The purpose of a scoping meeting is to identify significant geological processes in a park's ecosystem and determine if those processes are being affected by human activities. Pertinent human influences may include visitor impacts, park management practices and developments, land use adjacent to parks (e.g. pollutants, timber harvest), and global issues (e.g. industrial dust from China).

In addition, resource management issues related to geology and geological processes will be identified; and inventory, monitoring, and research studies that can provide scientific data to be used in making management decisions will be recommended.

How does the Geoindicators scoping process work?

The GRD coordinates efforts between park resource managers and geologists (from federal and state agencies and academia) through scoping meetings that are held in national parks. The scoping meetings are designed to use the participants' expertise and knowledge and build on the synergy of the participants through field trips, group discussion, and the exchange of ideas. For park staff, the scoping meetings foster a better understanding of the physical resources and geological processes in the park. For scientists, the scoping meetings foster an awareness of management issues and the decision-making and planning processes performed by park staff.

The field trip portion of a scoping meeting highlights the setting and geology of the park, as well as key resource management issues related to geological processes. During the discussion portion of a scoping meeting, selected geoindicators, specific to a park's setting, guide and focus the dialog.

The following questions are addressed during the group discussion of a scoping meeting. The answers are rated and prioritized.

- What are the significant geological processes in the park's ecosystems? Why are they significant?

- Which of these geological processes is being influenced by human activities both from inside and outside the park?

- How significant to park management are the identified geological processes and associated human influences?

- What sort of geological baseline data would benefit the park?

- What geoindicators should be monitored in the park? What protocols are recommended and who are the geoscientists to contact?

- Where are the information gaps? What studies or research are recommended?

What are the outcomes of a Geoindicators scoping meeting?

Scoping meetings provide an opportunity for park staff and geologists to connect and build relationships. This is significant because many park managers do not have easy access to geological expertise, and most do not have geologists on staff or in their regional offices.

Managers from participating parks will receive a summary report that highlights the recommendations identified during the scoping meeting. Recommendations include inventory and monitoring, which provides information for park planning and decision-making, and research topics that will fill information gaps.

Where can I get more information?

- Web site about geologic resource monitoring in the U.S. National Parks: http://www2.nature.nps.gov/grd/geology/monitoring/index.htm

- Detailed descriptions of the 27 geoindicators: http://www2.nature.nps.gov/grd/geology/monitoring/parameters.htm.

- Web site of the IUGS Geoindicators Initiative: http://www.lgt.lt:8080/geoin/welcome.

3.4 APPENDIX 5: GEOINDICATOR DESCRIPTIONS

The descriptions of geoindicators that follow were adapted from the geoindicators checklist developed by the International Union of Geological Sciences through its Commission on Geological Sciences for Environmental Planning. Each geoindicator includes a brief description, reasons for its significance to an ecosystem, and some examples of human influences from national park settings. The National Park Service uses these descriptions to facilitate discussion during scoping sessions in national parks. The purpose of a scoping meeting is to identify significant geological processes in a park's ecosystem and determine if those processes are being affected by human activities. For each scoping session, geoindicators are selected from the list of 27, as appropriate to the terrain and environmental issues under consideration.

Coral chemistry and growth patterns

Brief Description: Corals can be used to monitor environmental changes in the oceans and nearby coastal zone. The health, diversity, and extent of corals, and the geochemical makeup of their skeletons, record a variety of changes in the ocean surface water. These include temperature, salinity, fertility, insolation, precipitation, winds, sea levels, storm incidence, river runoff, and human inputs. Corals in coastal waters are susceptible to rapid changes in salinity and suspended matter concentrations and may be valuable indicators of the marine dispersion of agricultural, urban, mining, and industrial pollutants through river systems, as well as the history of contamination from coastal settlements.

Significance: The combination of abundant geochemical tracers, sub-annual time resolution, near-perfect dating capacity, and applicability to both current and past climatic changes establishes corals as one of the richest natural environmental recorders and archives.

Human influence: Corals respond to both natural changes in the marine environment and to anthropogenic pollution.

Desert surface crusts and fissures

Brief Description: The appearance or disappearance of thin (mm to cm) surface crusts in playas and depressions in arid and semi-arid regions may indicate changes in aridity. The formation of persistent deep, polygonal cracks in the mud and silt floors of closed basins and depressions may indicate the onset of desertification or severe drought. Surfaces may contain other desiccation features such as sedimentary dikes, evaporite deposits (especially gypsum and halite), adhesion ripples and large salt polygons.

Physical soil crusts (thin layer with reduced porosity and increases density at the surface of the soil) and biological soil crusts (a living community of lichen, cyanobacteria, algae, and moss growing on the soil surface and binding it together) are also significant indicators of the state of an ecosystem. Recovery of biological crusts may take decades to hundreds of years. The amount and extent of degradation to soil crusts are excellent indicators of physical disturbance to an area.

Significance: Desert surface crusts are important because they protect the underlying fine material from wind erosion. Physical and biological crusts; in Canyonlands and Arches national parks, for instance; generally help to control wind erosion. Biological crusts fix atmospheric nitrogen for vascular plants; provide carbon to the spaces between vegetation; secrete metals that stimulate plant growth; capture dust (i.e., nutrients) on their rough, wet surface areas; and decrease surface albedo. Depending on soil characteristics, biological crusts may increase or reduce the rate of water infiltration. By increasing surface roughness, they reduce runoff, thus increasing infiltration and the amount of water stored for plant use.

Human Influences: The formation of surface crusts is related primarily to natural causes, but hydrological regimes that affect crust formation and persistence may be altered by human activities, such as river diversion and groundwater extraction. Both physical and biological crusts can be affected by physical disturbances caused by wheeled or tracked vehicles, livestock hooves, and hiking and cycling. The impact is determined by the severity, frequency, and timing of the disturbance and by the size of the disturbed area.

Dune formation and reactivation

Brief Description: Dunes and sand sheets develop under a range of climatic and environmental controls, including wind speed and direction, and moisture and sediment availability. In the case of coastal dunes, sea-level change and beach and nearshore conditions are important factors. Organized dune systems and sheets in continental environments form from sediment transported or mobilized by wind action. New generations of dunes may form from sediment remobilized by climatic change and/or human disturbances.

Sand movement is inhibited by moisture and vegetation cover, so that dunes can also be used as an indicator of near-surface moisture conditions. Changes in dune morphology or position may indicate variations in aridity (drought cycles), wind velocity and direction (see Wind erosion), or disturbance by humans.

Significance: Moving dunes may engulf houses, fields, settlements, and transportation corridors. Active dunes in sub-humid to semi-arid regions decrease arable land for grazing and agriculture. They also provide a good index of changes in aridity. Coastal dunes are important determinants of coastal stability, supplying, storing, and receiving sand blown from adjacent beaches. Dunes play an important role in many ecosystems (boreal, semi-arid, desert, coastal) by providing morphological and hydrological controls on biological gradients.

Human Influence: Widespread changes can be induced by human disturbance, such as alteration of beach processes and sediment budgets, destruction of vegetation cover by trampling or vehicle use, overgrazing, and the introduction of exotic species.

Dust storm magnitude, duration, and frequency

Brief Description: The frequency, duration, and magnitude (intensity) of dust storms are gauges of the transport of dust and other fine sediments in arid and semi-arid regions (see Wind erosion). Desert winds carry more fine sediment than any other geological agent. An increased flux of dust has been correlated with periods of drier and/or windier climates in arid regions, historically and from proxy records in ocean and ice cores.

Significance: Local, regional, and global weather patterns can be strongly influenced by accumulations of dust in the atmosphere. Dust storms remove large quantities of surface sediments and topsoil with nutrients and seeds. Wind-borne dust, especially where the grain size is less than 10 µm, and salts are known hazards to human health. Dust storms are also an important source of nutrients for soils in desert margin areas.

Human Influence: Dust storms are natural events, but the amount of sediment available for transport may be related to surface disturbances such as overgrazing, tilling, or removal of vegetation. Dust storms cause hazardous travel conditions, abrasion of structures, burial of highways and railroad tracks, and removal of top soil. In addition, dust storms transport contaminated sediment great distances as from the Sahara Desert in North Africa to the coral reefs of the Caribbean.

Frozen ground activity

Brief Description: In permafrost and periglacial areas and in temperate regions where there is extensive seasonal freezing and thawing of soils, a wide range of processes lead to a variety of surface expressions, many of which have profound effects on human structures and settlements, as well as on ecosystems.

These sensitive periglacial features are found around glaciers, in high mountains (even at low-latitudes) and throughout polar regions. The development (aggradation) or degradation of permafrost is a sensitive and early indicator of climate change (see Subsurface temperature regime). Important geological parameters related to permafrost regions include: (1) Thickness of the active layer, the zone of annual freezing and thawing above permafrost; (2) Frost heaving, a physical process associated both with near surface winter freezing and with deeper permafrost aggradation. (3) Frost cracks, steep fractures formed by thermal contraction in rock or frozen ground with substantial ice content. (4) Icings, which are sheet-like masses of layered ice formed on the ground surface, or on river or lake ice, by freezing successive flows of water that may seep from the ground, flow from a spring or emerge from below river or lake ice through fractures. (5) Thermoerosion, erosion by water combined with its thermal effect on frozen ground; (6) Thermokarst, a range of features formed in areas of low relief when permafrost with excess ice thaws, including hummocks and mounds, water-filled depressions, “drunken” forests, mud flows, and other forms of thaw settlement; and, (7) Creep, slow downslope movement of rock and soil.

Significance: Permafrost influences natural and managed ecosystems, including forests, grasslands and rangelands mountains and wetlands, and their hydrological systems. It is an agent of environmental change that affects ecosystems and human settlements. Permafrost may enhance further (global) climate change by the release of carbon and other greenhouse gases during thawing. Permafrost can result in serious and costly disruptions from ground subsidence, slope failure, icings, and other cryogenic processes.

Human Influence: The freezing and thawing of soils and surficial materials and the consequent ground changes are natural processes controlled by climatic conditions, and can be modified by human actions in and around settlements and engineering works. Frozen ground activity such as frost heave, patterned ground development, and solifluction is a major geologic process active in high alpine areas. Patterned ground features are thought to form from frost heave and frost cracking and are extremely sensitive to human disturbance.

Glacier fluctuations

Brief Description: Changes in glacier movement, length, and volume can exert profound effects on the surrounding environment. For example, sudden melting (glacial outbursts) can generate catastrophic floods, or surges that trigger mud or debris flows. Movement along a fault may trigger a surge. Standard parameters include mass balance and the length of a glacier, which determines the position of the terminus. The location of the terminus and lateral margins of ice exerts a powerful influence on nearby physical and biological processes. Changes in the discharge of water from glaciers are indicators of glacier hydrology. Abrupt changes may warn of impending acceleration in melting, cavitation, or destructive flooding.

Significance: Glaciers are highly sensitive, natural, large-scale, representative indicators of the energy balance at the earth's surface in polar regions and high altitudes. Their capacity to store water for extended periods exerts significant control on the surface water cycle. The advance and retreat of mountain glaciers creates hazards to nearby human structures and communities through avalanches, slope failure, catastrophic outburst floods from ice and moraine-dammed lakes.

Human Influence: Glaciers grow or diminish in response to natural climatic fluctuations. They record annual and long-term changes and are practically undisturbed by direct human actions. Nevertheless, local glacial advances, the length of mountain glaciers, and their ice volume have decreased throughout the world providing evidence for global climate warming, possibly human induced.

Groundwater quality

Brief Description: The chemistry (quality) of groundwater reflects inputs from the atmosphere, from soil and water-rock reactions (weathering), as well as from pollutant sources such as mining, land clearance, logging, agriculture, acid precipitation, and domestic and industrial wastes. The relatively slow movement of water through the ground means that residence times are generally orders of magnitude longer than in surface waters. As in the case of surface water quality, it is difficult to simplify to a few parameters. However, a few important parameters can be used in most circumstances to assess significant processes or trends at a time-scale of 50-100 years: salinity, acidity, radioactivity, agricultural pollution (eg. nitrates, total dissolved organic carbon, pesticides and herbicides), mining pollution and urban runoff. Groundwater quality may also be affected by landslides, fires, and other surface processes that increase or decrease infiltration.

Significance: Groundwater is important for human consumption on a global scale, and changes in quality can have serious consequences. It is also important for the support of habitat and for maintaining the quality of base flow to rivers. The chemical composition of groundwater is a measure of its suitability as a source of water for human and animal consumption, irrigation, and for industrial and other purposes. It also influences ecosystem health and function, so that it is important to detect change and early warnings of change both in natural systems and resulting from pollution.

Human Influence: Changes in groundwater conditions may occur over a relatively short time scale and can be measured at in water wells or spring. Superimposed on these, however, are the greater impacts of the human activities. For example, landfills often contain hazardous substances such as paint thinners, herbicides, pesticides, human wastes, and waste oil. Soils and alluvium composed of loose sandy material of high permeability have a high potential for groundwater contamination.

Groundwater chemistry in the unsaturated zone

Brief Description: As water moves down through porous soils and sediments under favorable conditions it may preserve a record of weathering processes, climatic variations, and human activities such as agriculture (nitrates) and acidification. This indicator may be the output from the soil zone and reflect changes in soil properties. Rates of downward movement are typically 0.1 to 1.0 m/yr., and a record of individual events (20+ years) may be preserved over a scale of decades or centuries (see Groundwater quality; Soil quality). The unsaturated zone is also an important buffering zone for attenuation of acidity, metal content, and other potentially harmful substances.

Significance: Changes in recharge rates have a direct relationship to water resource availability. The unsaturated zone may store and transmit pollutants, the release of which may have a sudden adverse impact on groundwater quality.

Human Influence: Depending on land use, the unsaturated zone beneath a site may record the effects of human activities such as agriculture and industrial activity, or regional problems such as acidic deposition.

Groundwater level

Brief Description: Groundwater is replenished from precipitation and from surface runoff. The withdrawal rate by humans may exceed the rate of natural recharge, leading to reduction of the resource. In alluvial plains, reduction in streamflow reduces the rate of natural recharge to aquifers. Regular periodic measurements of water levels in wells and springs provides an indicator of changes in groundwater level. However, many springs are be perennial, intermittent, or periodic, and their discharge may depend on other factors such as changes in climate, tides, and local underground conditions.

Significance: The availability of clean water is of fundamental importance to the sustainability of life. It is essential to know how long the resource will last and to determine the present recharge.

Human Influence: There are natural changes in groundwater levels because of climate change (e.g., drought), but the most significant changes are due to human usage. In many places artificial recharge of aquifers is accomplished by injecting surface water into subsurface aquifers or as an indirect result of irrigation. Primary groundwater withdrawal concerns include (1) excessive groundwater withdrawals lowering the local water table, and potentially lowering surface water levels; large-scale, sustained pumping decreasing aquifer discharge, impacting streams and estuaries; and, in coastal areas the groundwater may be depleted to a point where salt water intrudes and contaminates the fresh groundwater.

Karst activity

Brief Description: Karst is a type of landscape found on carbonate rocks (limestone, dolomite, marble) or evaporites (gypsum, anhydrite, salt) and is typified by a wide range of closed surface depressions, well-developed underground drainage system, and a paucity of surface streams. The highly varied interactions among chemical, physical, and biological processes have a broad range of geological effects including dissolution, precipitation, sedimentation, and ground subsidence. Diagnostic features such as sinkholes, sinking streams, caves, and springs are the result of the dissolution action of circulating groundwater. Most of this underground water moves by laminar flow within narrow fissures, which may become enlarged above, at, or below the water table to form subsurface caves, in which the flow may become turbulent. Caves contain a variety of dissolution features, sediments, and speleothems, all of which may preserve a record of the geological and climatic history of the area. Karst deposits and landforms may persist for extraordinarily long times in relict caves and paleokarst. Karst can be either a sink or a source of CO_2, for the karst process is part of the global carbon cycle in which carbon is exchanged between the atmosphere, surface and underground water and carbonate minerals. Dissolution of carbonates, which is enhanced by the presence of acids in water, ties up carbon derived from the rock and from dissolved CO_2 as aqueous HCO_3-. Deposition of dissolved carbonate minerals is accompanied—and usually triggered—by release of some of the carbon as CO_2.

Significance: Karst systems are sensitive to many environmental factors. The presence and growth of caves may cause short-term problems, including bedrock collapse, disparities in well yields, poor groundwater quality because of lack of filtering action, instability of overlying soils, and difficulty in designing effective monitoring systems around waste facilities. Instability of karst surfaces causes damage to roads, buildings and other structures. Radon levels in karst groundwater tend to be high in some regions, and underground solution conduits can distribute radon unevenly throughout a particular area.

Human Influence: Natural karst processes can be influenced by human activities such as land-use modification (e.g., deforestation), waste disposal, and opening or blocking of cave entrances, all of which can substantially affect sedimentation, speleothem deposition, and groundwater quality. Sinkhole collapse can be triggered by lowering of the water table by over pumping or by the introduction of contaminants such as acids which weaken the rock inducing ground failure.

Lake levels and salinity

Brief Description: Lakes are dynamic systems that are sensitive to local climate and to land-use changes in the surrounding landscape (see Shoreline position). Some lakes receive their water from precipitation, some are dominated by runoff, and others are controlled by groundwater systems. On a time scale ranging from days to millennia, the aerial extent and depth of water in lakes are indicators of changes in climatic conditions such as precipitation, radiation, temperature, and wind speed. Lake level fluctuations vary with the water balance of the lake and its catchment, and may, in certain cases, reflect changes in shallow groundwater resources.

Significance: The history of fluctuations in lake levels provides a detailed record of climate changes. Lakes can be valuable indicators of near-surface groundwater conditions. Where not directly affected by human actions, lake level fluctuations are excellent indicators of drought conditions. Seasonally-flooded lake basins (playas) are dynamic landforms which reflect local hydrologic changes, and which react to short-term climate changes (e.g., rate of evaporation). Fluctuations in salinity also provide an indication of changes in conditions at the surface (climate, inflow/outflow relations) and in shallow groundwater (see Sediment sequence and composition; Surface water quality).

Human Influences: Lake levels can be influenced by human-induced climate change, and by human engineering, such as dams and channels. Lakes and ponds are often drained or pumped dry for municipal or agricultural use. Many natural lakes have been engineered so that lake levels are artificially raised and lowered for water storage, navigation, or recreation.

Relative sea level

Brief Description: The position and height of sea relative to the land determines the location of the shoreline (see Shoreline position). Though global fluctuations in sea level may result from the growth and melting of continental glaciers, and large-scale changes in the configuration of continental margins and ocean floors, there are many regional processes that result in rise or fall of relative sea level that affect one coastline and not another. These include: thermal expansion of ocean waters, glacial and ice pack fluctuations, crustal rebound from glaciation, uplift or subsidence in coastal areas related to various tectonic processes (e.g., isostasy), fluid withdrawal, and sediment deposition and compaction.

Significance: Changes in relative sea level may alter the position and morphology of coastlines, causing coastal flooding, saturation of soils, and a loss or gain of land. They may also create or destroy coastal wetlands and salt marshes, inundate coastal settlements, and induce salt-water intrusion into aquifers, leading to salinization of groundwater. A changing the relative sea level may also have effects on coastal structures and communities. Low-lying coastal and island states are particularly susceptible to sea-level rise.

Human Influences: Human actions including drainage of wetlands, withdrawal of groundwater, and deforestation, which reduces terrestrial water storage capacity, may contribute to global rise in sea level. Human-induced climate change is also of obvious importance. Large engineering works, such as river channeling or dam construction, that influence sediment delivery and deposition in deltaic areas may cause local changes.

Sediment sequence and composition

Brief Description: Lakes, wetlands, streams, estuaries, reservoirs, shallow coastal seas, and other bodies of marine or fresh water accumulate deposits derived from bedrock, soils, and organic remains within the drainage basin. Fine particles can be blown in by wind from natural, urban, and industrial sources. These deposits may preserve a record of past and present environmental events, both natural and human-induced, including soil erosion, air-transported particulates, solute transport, and slope failure. Some of these bodies of water are dynamic and sensitive systems whose deposits preserve a chronologically ordered and resolvable record of physical and chemical changes through their mineralogy, structure, and geochemistry. The remains of aquatic organisms can be correlated with various environmental parameters. Fossil pollen, spores, and seeds reflect past terrestrial and aquatic vegetation. These deposits can provide an indication of the impacts of past events on the system, and a baseline for comparison with contemporary environmental change.

Significance: The chemical, physical, and biological character of aquatic sediments can provide a finely resolvable record of environmental change, in which natural events may be clearly distinguishable from human input.

Human Influence: Sediment deposition is a natural process that can be strongly influenced by human activities such as land clearing, agriculture, logging, acidification, eutrophication, and industrial pollution. An area stripped of vegetation is subject to increased erosion. The eroded material (soil, regolith, or bedrock) is washed into streams to be eventually deposited within the drainage basin or sediment catchment. The sediment record will reflect this in the nature and thickness of the deposited material.

Seismicity

Brief Description: Movements along faults result in earthquake activity at the surface. Though usually such movement is a natural phenomenon, it can also be human-induced. Earthquakes can result in changes in the landscape, depending on the magnitude of the earthquake, the location of its epicenter, and local soil and rock conditions (see Surface displacement). To avoid, reduce, or warn of environmental impacts, it is necessary to know the size, location, and frequency of seismic events. These parameters can identify active faults and the direction of motion along them. Also of great importance is the spatial pattern of seismicity, including the presence of seismic gaps, and the relationship to known faults and active volcanoes. At least three, and generally more, monitoring sites are required to determine the necessary parameters. There are many national, regional, and international seismic networks, which provide information about the location, size, and motion of earthquakes anywhere in the world. However, shallow-focus tremors of lower magnitude, may not be detected by these means, and must be monitored more closely, on a local basis. Seismic hazard maps can be constructed to identify areas at varying risk from earthquake damage.

Significance: Earthquakes constitute one of the greatest natural hazards to human society. Surface effects include uplift or subsidence, surface faulting, landslides, debris flows, liquefaction, ground shaking, and tsunamis. Damage to buildings, roads, sewers, gas and water lines, power and telephone systems, and other built structures commonly occur.

Human Influence: Earthquakes are predominantly natural events. However, shallow-focus seismic tremors can be induced by human actions that change near-surface rock stresses or fluid pressures. These actions include: extracting or injecting water, gas, petroleum, or waste fluids into the ground for storage or for secondary hydrocarbon recovery; mining or quarrying activities; and loading the surface with large water bodies (reservoirs). Underground explosions, particularly for nuclear testing, can also generate seismic events.

Shoreline position

Brief Description: The position of the shoreline around lakes, reservoirs and oceans varies over a broad spectrum of time scales in response to shoreline erosion (retreat) or accretion (advance), changes in water level, and land uplift or subsidence (see Relative sea level). Long-term trends in shoreline position may be masked in the short term by variations over periods of days to years, related, for example, to storms events, El Niño/La Niña effects and ocean oscillation effects. Shoreline position reflects the coastal sediment budget, and changes may indicate natural or human-induced effects along-shore or in nearby rivers which supply sediment. The detailed shape and sedimentary character of a beach (e.g. slope, sediment size and shape, morphology, dune activity, etc.) are highly sensitive wave energy and attack angle, storm surges, tides, and nearshore circulation.

Significance: Changes in the position of the shoreline affect coastal transportation routes, installations, communities, and ecosystems. The effects of shoreline erosion on coastal communities and structures can be drastic and costly. It is of paramount importance for coastal settlements to know if local shorelines are advancing, retreating, or stable.

Human Influence: Erosion and sediment accretion are on-going natural processes along all coasts. Human activities such dredging, armoring, beach nourishment, beach engineering (jetties, groins, etc.), and the removal of vegetation can profoundly alter shoreline processes, position, and morphology by affecting the sediment supply. Control of rivers by damming can cut off the sediment supply thereby starving a beach of new sediment.

Slope failure

Brief Description: The way in which slopes fail depends on the angle of slope, the water content, the type of material involved, and local environmental factors such as ground temperature. Slope failure may take place suddenly and catastrophically or may be more gradual. Slope failure results in landslides, debris and snow avalanches, lahars, rock falls, debris flows, mud flows, slides, slumps, and creep. Landslides and mudflows in permafrost regions are mobilized and shaped by the freezing and thawing of pore water in the active layer. Failure can occur on slopes as low as 1°. Solifluction is the slow downslope movement of seasonally frozen and thawed saturated soil and regolith. Gentle to medium slopes with blankets of loose rock fragments overlying frozen ground may be subject to mass movements such as rock glaciers (see Frozen ground activity). Catastrophic slope failure can expose new frozen ground, setting off renewed mass wasting.

Climate change may accelerate or slow the natural rate of slope failure, through changes in precipitation or in the vegetation cover that binds loose slope materials. Wildfires can also promote mass movements by destroying tree cover. However, it is difficult to generalize where information is lacking on the present distribution and significance of landslides because many parameters, in addition to climate change, contribute to slope stability.

Significance: Slope failure causes death and significant property damage. Damage to ecosystems has not generally been documented, but landslides may destroy habitats, for example by blocking streams and denuding slopes.

Human Influence: Slope failure is a natural process that may be induced, accelerated, or retarded by human actions. Human influences include: (1) undercutting slopes for roads and other structures, quarrying, removal of retaining walls, and lowering of reservoirs; (2) Adding weight to slopes such as landfills, stockpiles of ore or rock, waste piles, construction of heavy buildings and other structures, fill, and retaining walls; (3) Vibrations from blasting, machinery, vehicles and aircraft; (4) Decrease of underlying support by mining; and, (5) Lubricating slopes with water from leaking pipelines, sewers, canals, and reservoirs.

Soil and sediment erosion

Brief Description: Erosion is the detachment of particles of soil and surficial sediments and rocks by fluvial processes, mass wasting and wind (see Stream sediment storage and load; Wind erosion). Both fluvial and wind erosion is generally greatest in arid and semi-arid regions, where soil is poorly developed and vegetation provides relatively little protection. Land use that causes soil disturbance greatly increases erosion above natural rates. Soil erosion also reduces the levels of the basic plant nutrients needed for growth, and decreases the diversity and abundance of soil organisms. The greater the water runoff, the less water enters the ground, reducing plant productivity.

Significance: Soil erosion is an important social and economic problem and an essential factor in assessing ecosystem health and function. Estimates of erosion are essential to issues of land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems. Stream sediment degrades water quality and provides a transporting medium for a wide range of chemical pollutants. Increased turbidity of coastal waters due to sediment load may adversely affect organisms such as benthic algae, corals, and fish.

Human Influences: Erosion is a fundamental and complex natural process that is strongly modified (generally increased) by human activities such as land clearing, agriculture, logging, construction, surface mining, and urbanization. Humans induce both water and wind erosion, which may result in chemical and physical deterioration of soil (see Soil quality).

Soil quality

Brief Description: Soils vary greatly in time and space. Over time-scales relevant to geoindicators, soils have both stable characteristics, such as mineralogy and relative proportions of sand, silt, and clay and those that respond rapidly to changing environmental conditions such as moisture, microorganisms (nematodes, mycorrhizal fungi, etc.) and ground freezing and thawing. Most soils resist short-term climate change, but some may undergo irreversible change such as lateritic hardening, podzolization, and large-scale erosion.

Chemical degradation takes place because of depletion of soluble elements through rainwater leaching, over-cropping and overgrazing, or because of the accumulation of salts precipitated from rising groundwater or irrigation schemes. It may also be caused by sewage containing toxic metals, precipitation of acidic and other airborne contaminants, as well as by persistent use of fertilizers and pesticides. A widespread problem is the retention in the soil organic matter and clay minerals of potentially toxic metals and radionuclides. These and other chemical components may be catastrophically released as what are commonly referred to as “chemical time bombs” where the pH of the soil is decreased by acidification or where other environmental disturbances (e.g., erosion, drought, land use change) intervene. Soils also act as a primary barrier against the migration of organic contaminants into groundwater. Key indicators are pH, organic matter content, sodium absorption ratio, cation exchange capacity, and cation saturation.

Significance: Soils are essential for the continued existence of life on earth. As a source of plant nutrients, soils have a major influence on terrestrial ecosystems. Soils continuously recycle plant and animal remains, and they are major support systems for human life, determining the agricultural production capacity of the land. Soils buffer and filter pollutants, store moisture and nutrients, and are important sources and sinks for carbon dioxide, methane, and nitrogen. Soils provide an archive of past climatic conditions and human influences. The soils of boreal regions are estimated to hold the equivalent of some 60% of the current atmospheric carbon. Long-term global warming is expected to increase decomposition and drying, thus potentially releasing huge volumes of methane and carbon dioxide. Key soil indicators are texture (especially clay content), bulk density, aggregate stability and size distribution, and water-holding capacity.

Human Influences: Human activities such as land clearing and compaction by machinery results in physical degradation of soils. Human activities cause increases in soil bulk density from agricultural practices and road operations. Acidification results from the use of inorganic fertilizers and from acid rain. Soil degradation is one of the largest threats to environmental sustainability. Soil structure may be altered by compaction, decreasing infiltration capacity and porosity and increasing bulk density and resistance to root penetration. These soils impede drainage and are quickly saturated. The resulting runoff can cause accelerated erosion and transport of pollutants such as pesticides (see Soil and sediment erosion).

Streamflow

Brief Description: Streamflow varies with the volume of water, precipitation, surface temperature, and other climatic factors. For most streams and rivers, the highest water discharge is found close to the sea, but in arid regions discharge decreases naturally downstream. Land use in drainage basins also strongly affects streamflow.

Significance: Streamflow directly reflects climatic variation. Stream systems play a key role in the regulation and maintenance of biodiversity. Changes in streams and streamflow are indicators of changes in basin dynamics and land use.

Human Influences: Natural variations in streamflow predominate, but they can be strongly modified by human actions, such as dams and reservoirs, irrigation, and diversion for use outside the watershed. Streamflow is also altered by the channelizing of natural streams, by impacts to bank slopes from extensive use (e.g., foot traffic, horse traffic, boating), and by the removal of vegetation and the natural vegetative canopy.

Stream channel morphology

Brief Description: Streams and rivers are dynamic landforms subject to rapid change in channel shape and flow pattern. Water and sediment discharge rates determine the dimensions of a stream channel (width, depth, meander wavelength and gradient). Dimensionless characteristics of stream channels, types of stream patterns (braided, meandering, straight) and sinuosity are significantly affected by changes in flow rate and sediment discharge, and by the type of sediment load (i.e., suspended load v. bed load (see Stream sediment storage and load). Dramatic changes in stream bank erosion within a short time period indicate changes in sediment discharge.

Significance: Channel dimensions reflect magnitude of water and sediment discharges. In the absence of hydrologic and streamflow records, an understanding of stream morphology can help delineate environmental changes of many kinds. Changes in stream pattern, which can be very rapid in arid and semi-arid areas, place significant limits on land use, such as on islands in braided streams and meander plains, or along banks undergoing erosion.

Human Influences: Significant changes in stream dimensions, discharge, and pattern may reflect human influences such as water diversion and increased sediment loads resulting from land clearance, farming, or forest harvesting. Such variations are also responsive to climatic fluctuations and tectonics.

Stream sediment storage and load

Brief Description: The sediment load, either in solution, suspension or as bed load of sand and gravel in stream channels reflects upland erosion within the drainage basin and changes in storage of sediment in alluvial bottomlands (see Soil and sediment erosion). In turn, climate, vegetation, soil and rock type, relief and slope, and human activities such as timber harvesting, agriculture, and urbanization influence stream sediment storage and load. Much of the sediment eroded from upland areas is deposited and stored on lower hill slopes, in bottomlands, and in lakes and reservoirs. Flash floods in ephemeral desert streams may transport very large sediment loads, accounting for unforeseen sedimentation problems downstream, especially behind reservoir dams.

Significance: Sediment load determines channel shape and pattern (see Stream channel morphology). Changes in sediment yield reflect changes in conditions in the drainage basin, including changes in climate, soils, erosion rates, vegetation, topography, and land use. Since nutrients are transported downstream with the sediment, fluctuations in sediment discharge affect a great many terrestrial and coastal processes, including ecosystem responses. For example, to reproduce effectively, salmon and trout need gravel stream beds for spawning and egg survival; silt and clay deposits formed by flooding or excessive erosion can destroy these spawning beds. Also, stream sediments are potential sources and sinks for contaminants.

Human Influences: Stream sediment storage and load is influenced strongly by human actions, such as in the construction of dams and levees, forest harvesting, and farming in drainage basins. Removal of vegetation and urbanization increases runoff, increases erosion, and therefore increases the amount of sediment load.

Subsurface temperature regime

Brief Description: Temperatures in wells and boreholes a few hundred meters deep can be an important source of information on recent climatic changes. The normal upward heat flow from the earth's interior and crust is altered by the downward propagation of heat from the surface. As temperature fluctuations are transmitted downward, they become progressively smaller, with shorter-period variations attenuating more rapidly than longer ones. Although seasonal oscillations may be undetectable below about 15 m, century-long temperature records may be observed to depths of 150 m or so. Bedrock thus selectively retains the long-term trends required for reconstructing climate change.

The subsurface temperature is strongly affected by local factors such as thickness and duration of snow cover, type of vegetation, properties of organic soil layers, depth to the water table, and topography. It influences, in turn, a wide range of ground and surface processes, particularly in the near-surface portions of permafrost (see Frozen ground activity). Below the active layer, where ground temperatures fluctuate seasonally as thawing and freezing take place, long-term temperature variations may be recorded. Here, repeated measurements of soil temperature at fixed locations can reveal both the long-term dynamics of seasonally frozen ground and long-term climatic fluctuations.

Significance: The thermal regime of soils and bedrock impacts the soil ecosystem, near-surface chemical reactions, and the ability of these materials to sequester or release greenhouse gases. It may affect the type, productivity, and decay of plants; the availability and retention of water; the rate of nutrient cycling; and the activities of soil microorganisms. It may also indicate changes in surface temperature over periods of up to 2-3 centuries, especially in regions without a record of past surface temperatures. In permafrost the ground temperature controls the mechanical properties of the soils, especially during the freeze-thaw transition in the active layer.

Human Influence: The subsurface temperature regime reflects both the natural geothermal flux from Earth's interior and the surface temperature. The latter can be modified by human actions, such as land clearing, wetland destruction, agriculture, deforestation, flooding of land for reservoirs, or development of large settlements that give rise to a "heat island" effect.

Surface displacement

Brief Description: The earth's surface is subject to small but significant displacements (uplift, subsidence, lateral movement, rotation, distortion, dilation) that affect both elevation and horizontal position. These movements may be the result of active tectonic processes, collapse into underground cavities (see Karst activity), or the compaction of surficial materials. Sudden movements may be caused by faulting associated with earthquakes (see Seismicity), and from the collapse of rock or sediment into cavities produced by near-surface mining (e.g., coal and solution-mining of salt). Slower local subsidence may also be induced by: fluid withdrawal (gas, oil, groundwater, geothermal fluids); densification or loss of mass in peat being developed for agriculture; drainage of surface waters from wetlands, which can cause oxidation, erosion, and compaction of unconsolidated soils and sediments; and filtration of surface water through porous sediments. Also, the land surface elevation responds to plate movements, compaction of sedimentary basins, and glacial rebound.

Significance: Most surface displacements have but minor effects on landscapes and ecosystems. However, there are exceptions, such as where drainage channels are suddenly displaced by faults, or where seismically-induced uplift raises intertidal zones above sea-level. Moreover, extraction of fluids beneath urban areas can induce land subsidence and cause flooding, especially of coastal communities near sea level. Subsidence damages buildings, foundations, and other built structures.

Human Influence: Surface displacements are natural phenomena associated with plate movements, glacial rebound, and faulting, but human activities such as extraction of groundwater, oil, and gas can also induce surface subsidence.

Surface water quality

Brief Description: The water quality of a lake, reservoir, river or wetland can vary in space and time according to natural morphological, hydrological, chemical, biological, and sedimentological processes (e.g., changes of erosion rates). The quality of surface water in rivers, streams, lakes, ponds, and wetlands is determined by interactions with soil, transported sediments, bedrock, groundwater, and the atmosphere. The bulk of the solutes in surface waters, however, are derived from soils and groundwater base flow where the influence of water-rock interactions are important.

Significance: Clean water is essential for the survival of all forms of life. Most is used for irrigation, with lesser amounts for municipal, industrial, and recreational purposes. Only 6% of all water is used for domestic consumption. Pathogens such as bacteria, viruses, and parasites are among the world's most dangerous environmental pollutants causing many water-borne diseases. Water quality data are essential for the implementation of responsible water quality regulations, for characterizing and remediating contamination, and for the protection of the health of humans and other organisms.

Human Influence: Pollution of natural bodies of surface water is widespread because of human activities, such as disposal of sewage and industrial wastes, land clearing, deforestation, use of pesticides, and hydroelectric development. Water quality may also be significantly affected by agriculture, industry, mineral and energy extraction, urban development and other human actions, as well as by atmospheric inputs. For example, impacts from cattle grazing include trampled soil and vegetation, increased sedimentation, and fecal contamination. Likewise, the use of herbicides to eradicate exotic species may cause water quality problems associated with streams and springs in units of the National Park Service.

Volcanic unrest

Brief Description: Volcanic unrest includes ground deformation, seismicity, emission of volcanic gases, geothermal activity, and elevated ground temperatures. Volcanic unrest can also be expressed by changes in the temperature, composition, and level of crater lakes, by melting of glaciers or by anomalous changes in glaciers and snow fields on volcanoes. Not all volcanic unrest culminates in eruptions. In many cases, the unrest results in a failed eruption in which the rising magma does not breach the surface and erupt.

Significance: Natural hazards associated with eruptions pose a significant threat to human and animal populations. Before 1900, two indirect hazards—volcanogenic tsunamis and post-eruption disease and starvation—accounted for most of the eruption-associated human fatalities. In the 20th century, however, direct hazards related to explosive eruptions such as pyroclastic flows and surges, debris flows, and mudflows were the most deadly hazards.

Human Influence: Volcanism is a natural process which has operated since the formation of the earth. Although a few attempts have been made to divert lava flows, humans have had no influence whatsoever on the underlying causes of volcanism. Geological mapping and dating of prior eruptions to reconstruct eruptive histories of high-risk volcanoes can help to reduce hazards to life and property.

Wetlands extent, structure, and hydrology

Brief Description: Wetlands are complex and sensitive ecosystems, characterized by a water table at or near the land surface for some part of the year. Soil conditions differ from adjacent uplands and vegetation has become adapted to wet conditions. Wetlands are usually classified on the basis of their morphology, vegetation type, and, to a lesser extent, their hydrology. Though definitions vary, the following types are widely recognized: coastal salt and freshwater marshes; swamps (mangrove, shrub, and wooded); wet grasslands, meadows and prairies; and peat bogs, in which organic sediments have accumulated to depths in excess of 30-50 cm (including mires, muskegs, and fens). The aerial extent, distribution, structure of a wetland can be altered by many processes, such as organic and inorganic sediment deposition and erosion, by and changing hydrology. In the case of coastal wetlands, saltwater intrusion and changes in sea level can also be important (see Relative sea level; Shoreline position).

Hydrological relationships play a key role in wetland ecosystem processes, and in determining structure and growth. An important geoindicator is the water budget of a wetland, which links inputs from groundwater, runoff, precipitation, and physical forces (wind, tides) with outputs from drainage, recharge, evaporation, and transpiration. Annual or seasonal changes in the range of water levels affect visible surface biota, decay processes, accumulation rates, and gas emissions. Such changes can occur in response to a range of external factors, such as fluctuations in water source (river diversions, groundwater pumping), climate or land use (forest clearing). Waters flowing out of wetlands are chemically distinct from inflow waters, because a range of physical and chemical reactions take place as water passes through organic materials, such as peat, causing some elements (e.g., heavy metals) to be sequestered and others (e.g., DOC, humic acids) to be mobilized. A baseline of wetland conditions may be established through a paleoecological study to investigate whether a present-day wetland is stable or actively evolving, and if so in what direction and at what rate.

Significance: Wetlands are areas of high biological productivity and diversity. They provide important sites for wildlife habitat and human recreation. Wetlands mediate large and small-scale environmental processes by altering downstream catchments. Wetlands can act as a filter, sequestering and storing heavy metals and other pollutants, such as mercury. Wetlands serve as flood buffers and as storm defenses and erosion controls in coastal areas. Wetlands can act as carbon sinks, storing organic carbon in waterlogged sediments. Wetlands can also be a carbon source, when it is released via degassing during decay processes, or after drainage and cutting, as a result of oxidation or burning.

Human Influence: Wetlands develop naturally in response to morphological and hydrological features of the landscape. Their evolution can be affected by external factors such as climate change, landscape processes (e.g., coastal erosion), or human activity such as the draining or swamps and wetlands, channeling of streams and rivers feeding the wetland, water removal and impoundment, and logging. Wetlands can be lost to drainage for agriculture or settlement or to harvesting for commercial purposes.

Wind erosion

Brief Description: The action of wind on exposed soils, sediments, and friable rocks results in the erosion and entrainment of sediment and soil particles (see Dust storm magnitude, duration and frequency). Aeolian action also forms and shapes dunes, yardangs, and other landforms. Subsurface deposits and roots are commonly exposed by wind erosion. Wind can also reduce vegetation cover in wadis and depressions, scattering the remains of vegetation in interfluves. Stone pavements may result from the removal of fine particles from the surface leaving a residue of coarse particles. Blowouts (erosional troughs and depressions) in coastal dune complexes are important indicators of changes in wind erosion (see Dune formation and reactivation). The potential for deflation is generally increased by shoreline erosion or washovers, vegetation die-back (due to soil nutrient deficiency or to animal activity), and human actions such as recreation and construction.

Significance: Changes in wind-shaped surface morphology and vegetation cover that accompany drought and desertification are important gauges of environmental change in arid lands. Wind erosion also affects large areas of croplands in arid and semi-arid regions, removing topsoil, seeds, and nutrients and then depositing the material hundreds or even thousands of mile away.

Human Influence: Wind erosion is a natural phenomenon, but the surfaces it acts upon may be made vulnerable by human actions, especially those, such as cultivation and over-grazing, that result in the reduction of vegetative cover and desertification. The action of wind can spread pollutants and toxic material worldwide (e.g. dust from China and the African Sahara).